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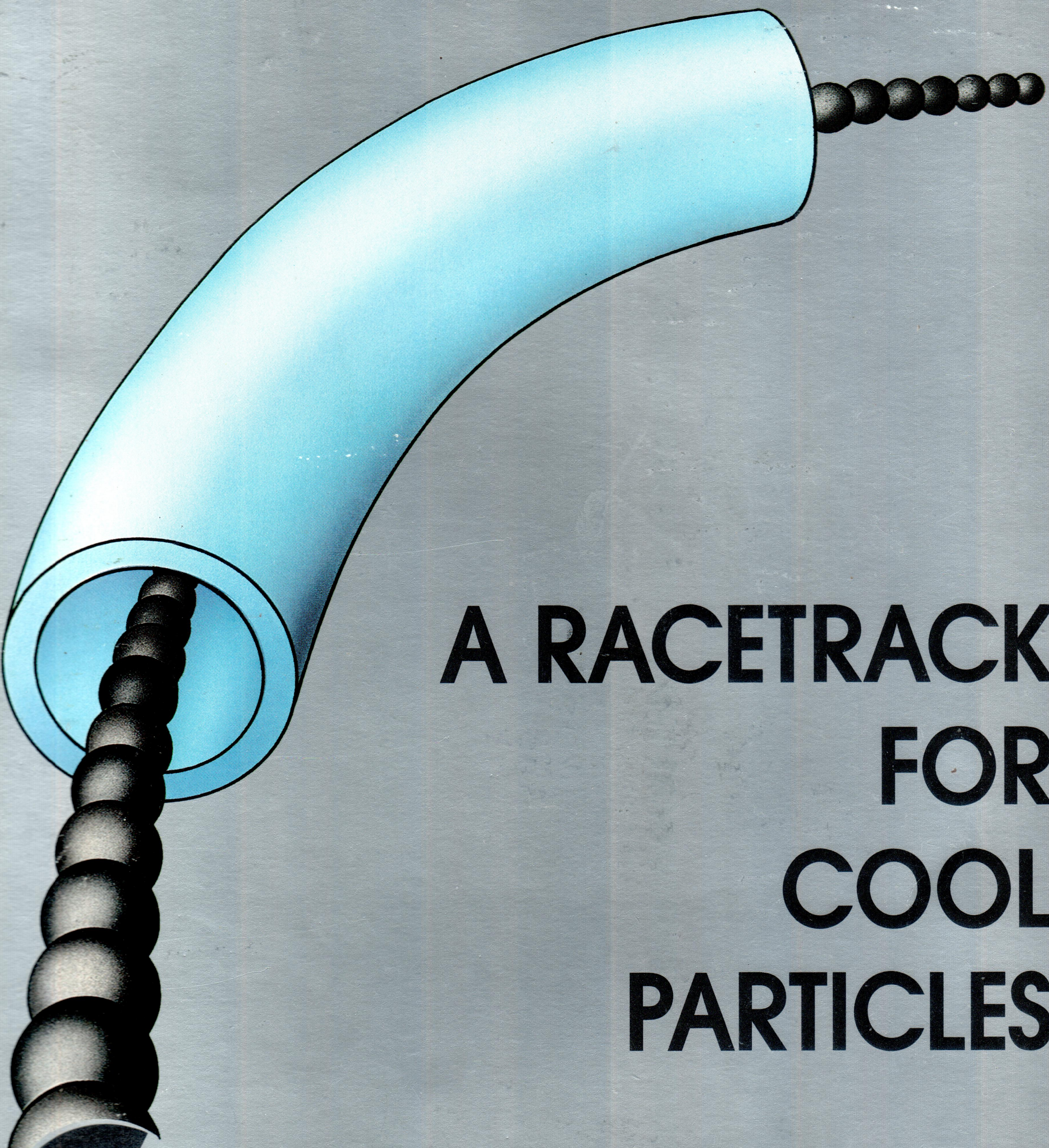

A RACETRACK FOR COOL PARTICLES

COSY • Jülich

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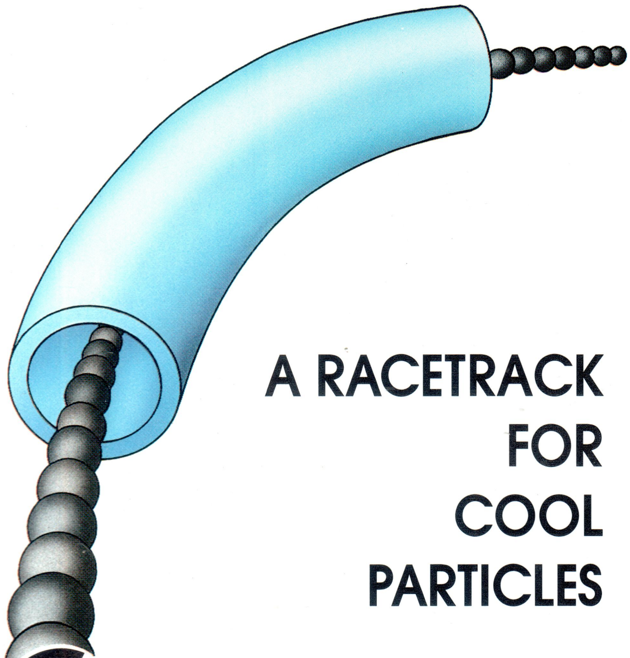

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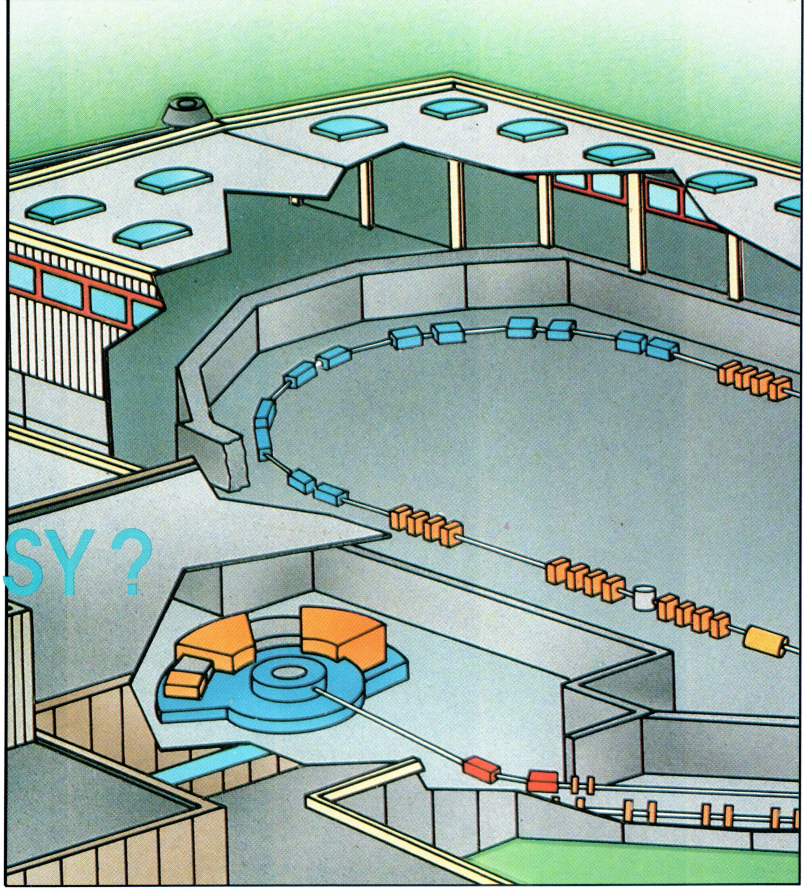
Content:



What is COSY?

It is the acronym for the COoler SYnchrotron at Jülich*, which is a storage ring for ion beams, especially for protons. These particles are delivered by the cyclotron JULIC at the KFA (Kernforschungsanlage Jülich GmbH). The new storage ring is essentially a large circular vacuum tube some 180 metres in circumference. The stored particles circulate about one million times per second and have to be focused and kept on track by appropriate magnetic guiding fields. The particle beam is extraordinarily dense and brilliant; it may be shaped in various ways to provide it with special properties.

Firstly, the energy of the particles may be varied by employing high frequency electromagnetic fields. This synchrotron acceleration boosts the final proton energy up to a maximum of 2.5 thousand million electron volts (GeV), though COSY is optimised for an energy of 1.5 GeV.

While circulating, the particles are subjected to a process called "beam cooling". The cooling of particle beams is a relatively new technique whose possibilities are far from exhausted. It is accomplished by two – basically different – methods, namely using electrons as a "coolant" or stochastic cooling, respectively.

In principle beam cooling reduces to a minimum the random movement of the individual particles around the ideal beam trajectory. A cooled beam is particularly well ordered and thus may be either aligned to almost perfect parallelity or focused to an extremely brilliant spot. This is a very attractive feature – very much like laser beams in optics: many precision experiments now become possible for the first time.

COSY's cooled beam will be used in various ways for experiments in basic research. It is either used "within" the ring or it may be extracted, i. e. made available outside the ring, where it hits an extremely thin layer of the material to be investigated, the target. The particles emerging from this collision are then studied.

COSY is conceived as an instrument for basic research in the domains of atomic physics, nuclear physics and "intermediate energy physics". The latter is a new field of research in between (high-energy) particle physics and (low-energy) nuclear physics in which "subnuclear structures" are studied.

*There is also a COSY facility at Berlin: a compact superconducting storage ring for electrons at the BESSY synchrotron laboratory.

COSY – National and International Perspectives

The combination of properties inherent to COSY render it unique among proton storage rings with cooling already in existence or under construction*. The outstanding features are the excellent beam quality, the high beam density or brilliance, a large range of available proton energies and the external utilisation of the beam.

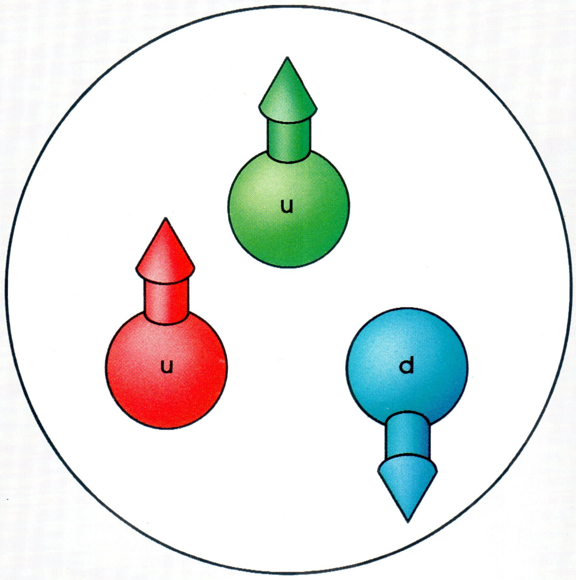
The future users of COSY have formed CANU – the user collaboration of the universities of North Rhine-Westphalia – which other interested university groups also have joined. CANU is intended to provided support for these groups and coordinate the plans between them and the KFA for the research work carried out with COSY.

Respected scientists from research institutions around the world advise the KFA on issues involving the design, construction and scientific exploitation of COSY.

Nuclear physics research has been carried out at the KFA for many years. COSY is the next step in investigating new questions in nuclear and intermediate energy physics. In this context it becomes very attractive to employ the existing large detector facilities at the IKP (Institute of Nuclear Research) of the KFA. Especially with JULIC as the injector cyclotron and the magnetic spectrometer BIG KARL new interesting experiments become feasible. But new equipment will also be developed and adapted to the special features of COSY.

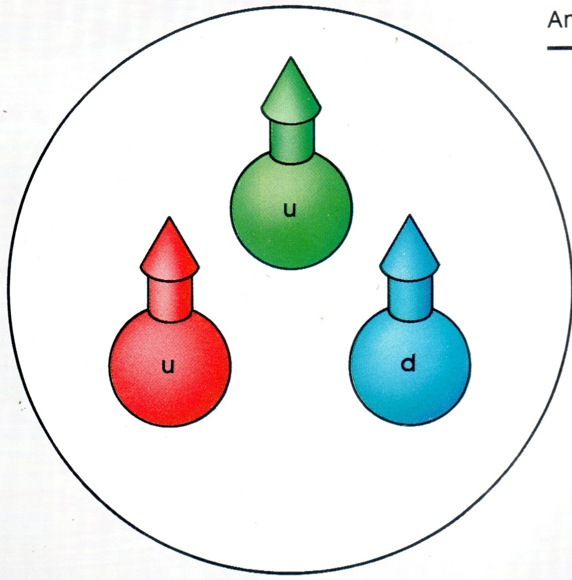
The KFA already takes part in international efforts to study problems of intermediate energy physics at the LEAR antiproton ring at CERN (Geneva). These activities will lead directly into the future research programme at COSY.

*CELSIUS (Sweden), IUCF (USA) and TARN (Japan)



a)

The Proton



An excited proton

c)

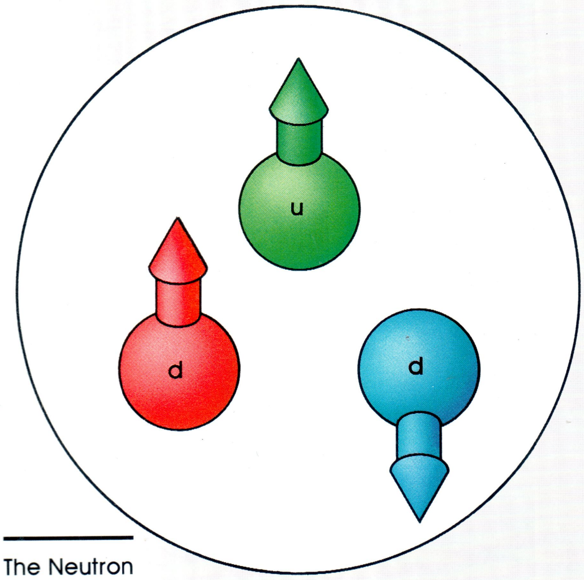
What are Hadrons?

Apart from those elementary stable particles which are the building blocks of our environment – protons, neutrons and electrons – a whole "zoo" of new particles has been observed at accelerators and in cosmic radiation since the middle of this century. These particles are unstable and decay.

The elementary particles have been grouped into families according to their characteristic properties. One of these families, the hadrons, consists of the baryons (i. e. protons, neutrons, hyperons etc.) and mesons. Members of the hadron family exert very strong forces on each other. (This strong interaction is the foundation of the very existence of atomic nuclei.)

The systematics of the hadron family suggest that they have common building blocks, so-called "quarks". Quarks again can be classified into three – successively discovered – groups or generations, with 2 quarks in each group, which differ amongst other features in mass. The first lightest group consists of the so-called "up quarks" and "down quarks" – which are the building blocks of the matter we encounter every day. Protons and neutrons consist of a combination of three of these quarks.

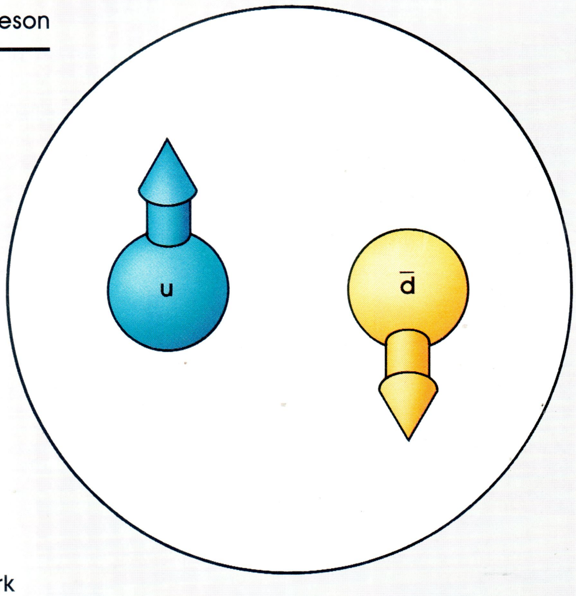
Each quark exhibits some type of gyroscopic motion, which is called spin. The relative direction of the quark spins to each other accounts for the mass of the particles formed from them. Hence not only protons (Fig. a) and neutrons (Fig. b) exist, but also their heavy, excited "relatives" (Fig. c).



The Neutron

b)

A positive π-Meson



u = up-quark

d = down-quark

$\bar{d}$ = anti-down-quark
with anticolour yellow

red, green and blue are the colour charges of the quarks.

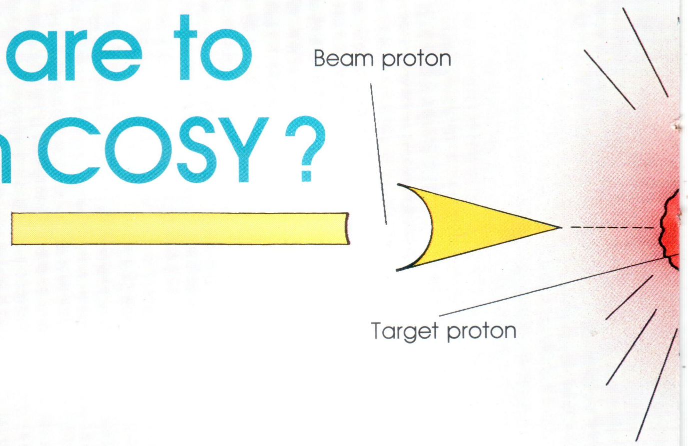
d)

In contrast to baryons with three quarks, mesons consist of a quark and an anti-quark (Fig. d). From many aspects antiparticles may be viewed as "mirror images" of the corresponding particles. Particle anti-particle pairs may be generated from energy or if they come into contact they are converted back into energy.

The heavy quarks of the second and third generation do not occur normally in nature. They can only be created as quark – antiquark pairs in energetic collisions and have so much mass that they decay immediately into lighter quarks, releasing energy in the process.

The energy range of COSY enables us to study the dynamics and the interaction of quarks of the first generation and the strange quarks of the second generation.

What Subjects are to be Studied with COSY?



COSY is intended to make important contributions towards clarifying numerous questions unanswered so far, such as:

- How do unstable hadrons – generated with COSY – interact? These particles are not available to the experimentalist in our natural environment. Of particular interest in this context is not only how they interact with protons, neutrons and atomic nuclei but also their mutual interaction.

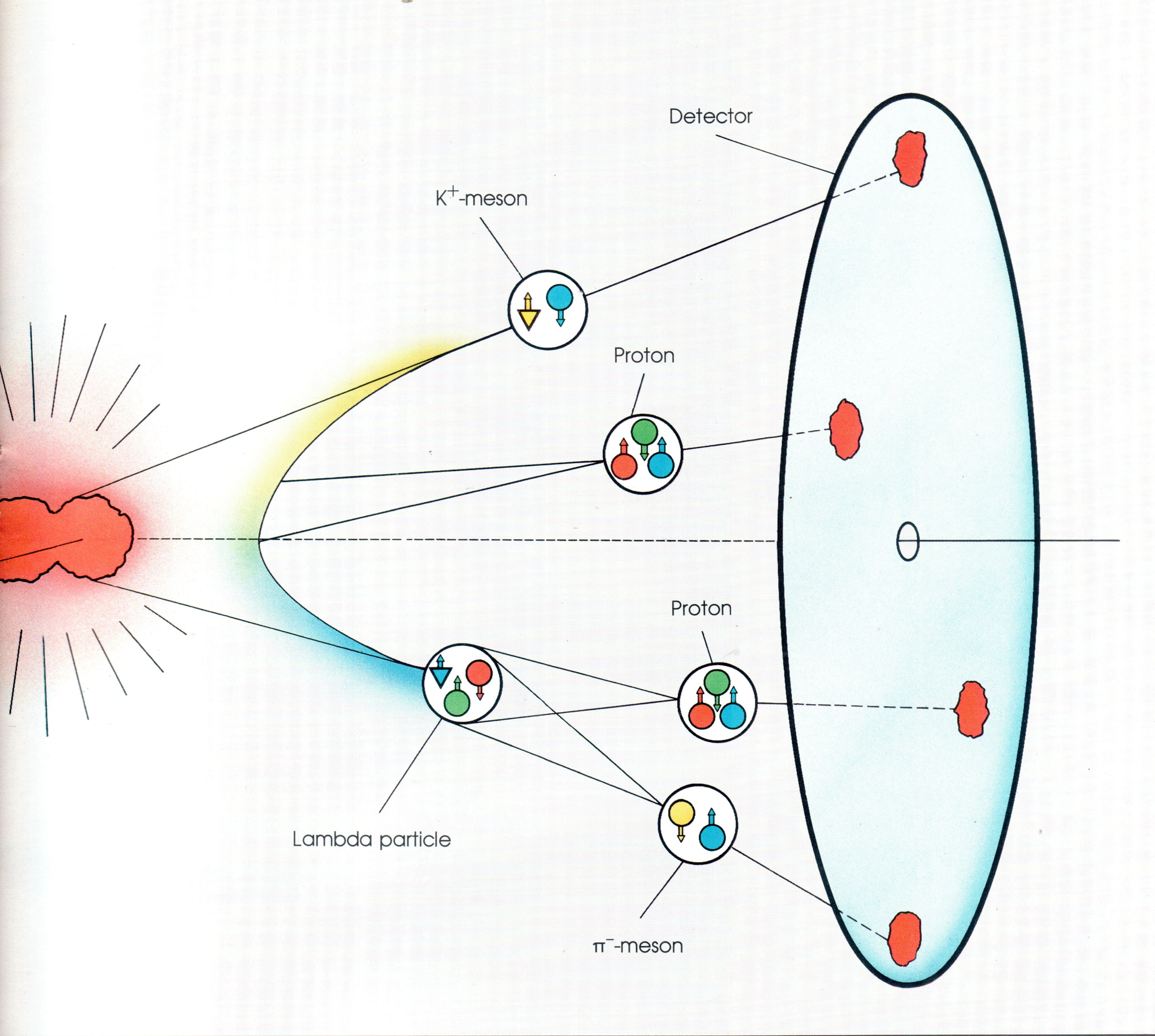
- Are there combinations other than the known ones, consisting of three quarks (baryons) and a quark-antiquark pair (mesons)?

- The mutual interaction of quarks is thought to be due to an exchange of "gluons". Are these gluons capable of forming new measurable particles as predicted by the theory?

- Is the quark structure of the baryons preserved in an atomic nucleus or does it change?

So far isolated quarks have not been "seen" in a detector. That is believed to be impossible in principle.

One possibility, though, of studying the behaviour of individual quarks with COSY would be to tag known particles with a quark which does not occur in nature and study the new compound particle (tracer method). An example is shown schematically in the figure.



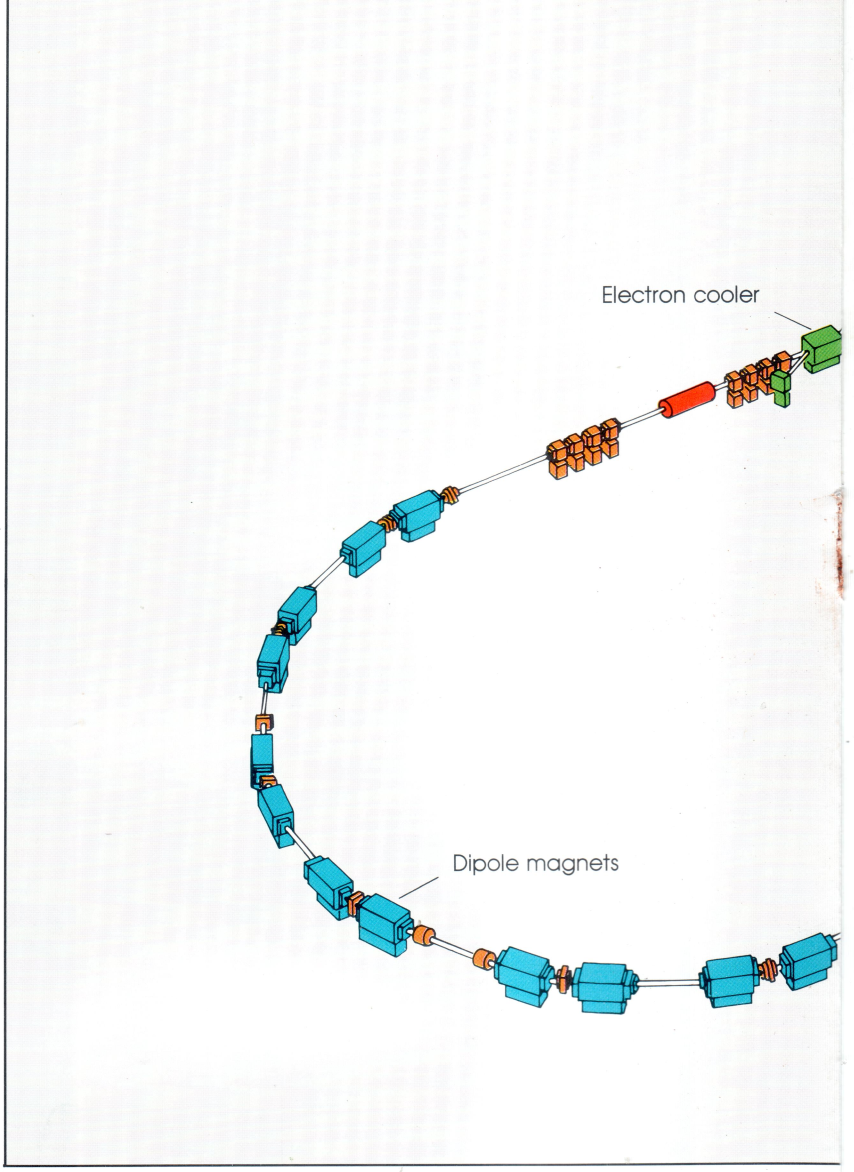
A COSY beam proton strikes a target proton. Provided there is sufficient energy three particles can be generated in the proton-proton collision: one lambda particle, one K^+-meson and one proton. Lambda particles and K^+-mesons are special, since they contain a strange or an anti-strange quark, which "tags" them. Those tagged particles decay after a certain time and the decay products may be tracked in the detector. For the lambda particle this is illustrated in the figure.

Various extremely sophisticated detectors have to be designed and built for these and other investigations. Only the outstanding beam quality of COSY allows us to exploit new detection methods to their full extent.

The Setup of COSY

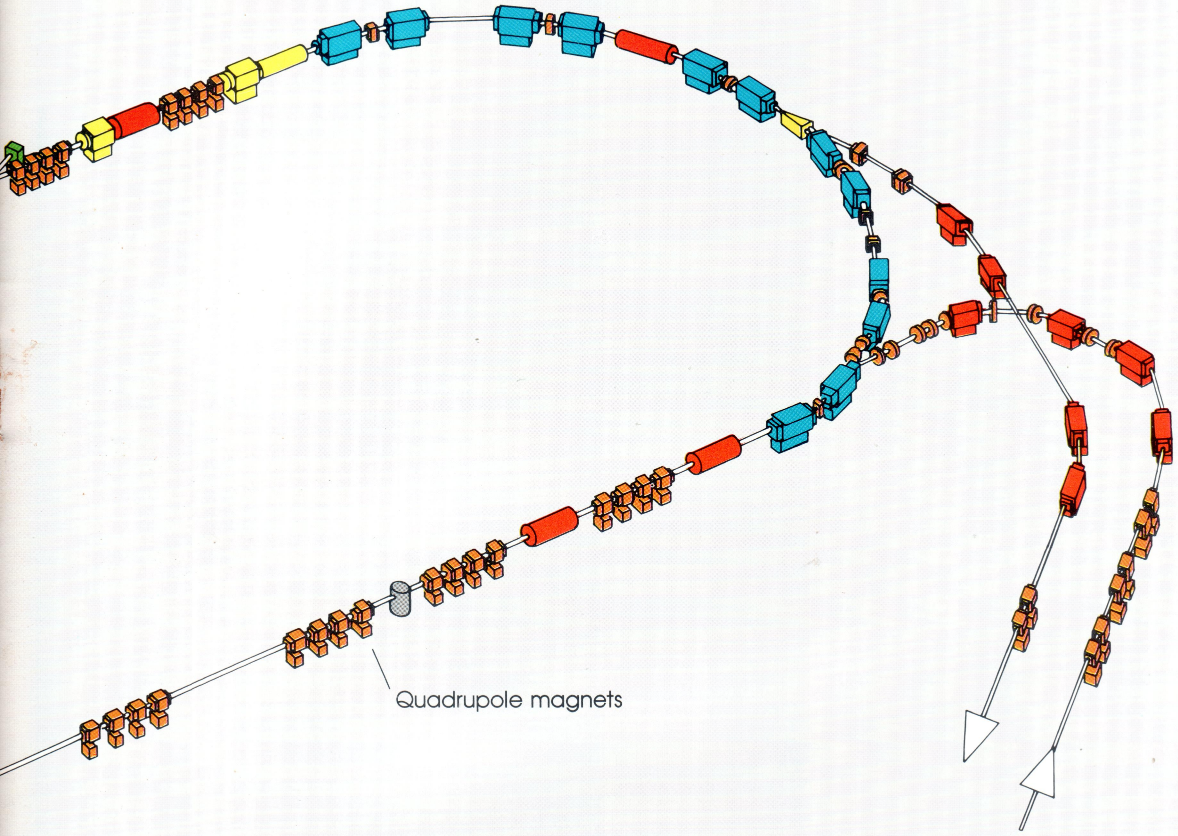
The cyclotron JULIC, serving as an injector for COSY delivers a beam of charged particles which is bent and focused by magnets. The beam travels through an evacuated tube to the COSY ring.

The beam pipe of COSY – pumped down to ultra-high vacuum – is shaped into a racetrack with two straight sections, each 40 m in length and two half-circles at the ends. Very much like lenses in ordinary light optics, magnets serve to keep the charged beam on track. Altogether, 24 dipole magnets deflect the beam around the curves, where 24 quadrupole magnets for focusing are also positioned. In the straight sections another 32 quadrupole magnets are provided.



The beam will be extracted from COSY close to the injection region. A series of extraction elements (septa, magnets etc.) is activated to shape the beam and deliver it to the external target locations.

The straight sections of COSY also contain the accelerating structures (RF cavities) and the electron cooler. In addition the devices needed for stochastic cooling are distributed around COSY at convenient locations.



COSY – main parameters		
Circumference		183.47 m
Vacuum requirements		10^{-10} mbar
Accelerator frequency		0.46 – 1.6 MHz
Proton injection energy		40 MeV
Proton final energy (max.)		2.5 GeV
Number of straight sections		2
Emittance of cooled beam		0.2 pi mm mrad
Dipole Magnets	Number	24
	Angle of deflection	15 degrees
	Core length	1832 mm
	Air gap	90 mm
	Magnetic field strength (max.)	1.58 T
	Bending radius	7.0 m
	Weight	27 t (app.)
Quadrupole Magnets	Number	56
	Core length	500 mm
	Aperture diameter	170 mm
	Magnetic field strength (max.)	7.8 T/m
	Weight	2 – 3 t

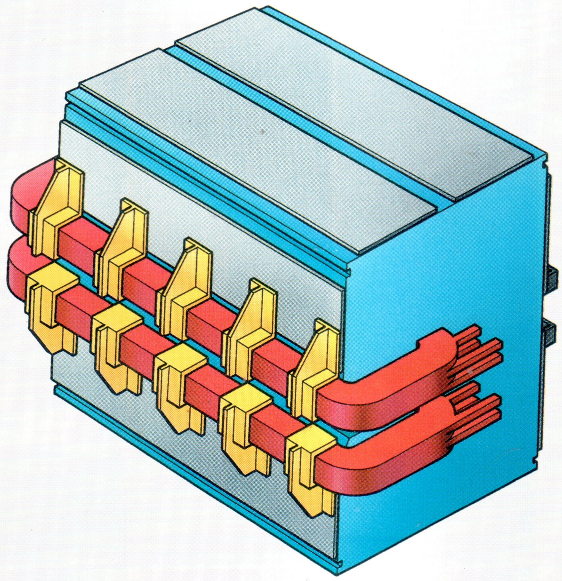
Magnets

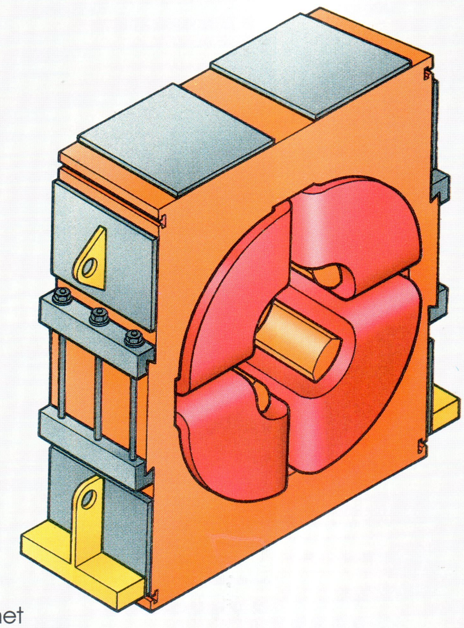
As mentioned before, magnets are employed to deflect and focus the beam around COSY. Since the energy of the beam increases rapidly once the beam is injected into COSY, the magnetic fields have to change, too. Therefore COSY magnets have a special, laminated iron structure which is contained in coils of hollow copper conductors, through which cooling water flows.

The most important specifications of the magnets are given below:

Dipoles	
Angle of deflection	15°
Air gap	90 mm
Core length	1832 mm
Weight	27 t
Number	24

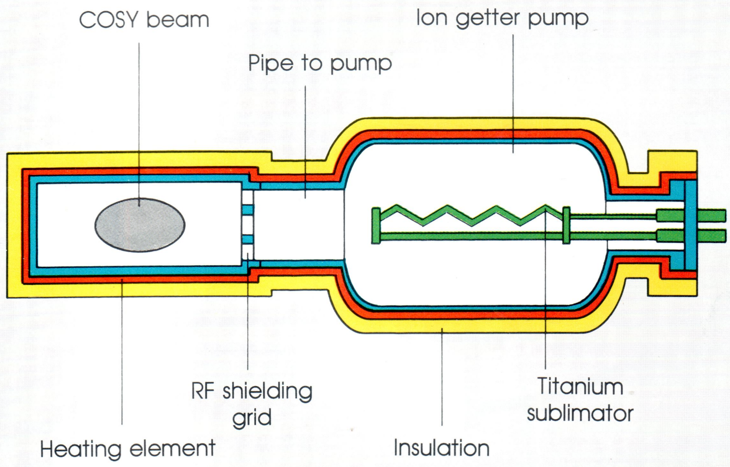
Quadrupoles	
Air gap	170 mm
Core length	500 mm
Weight	2 – 3 t
Number	56


Dipole magnet


Quadrupole magnet

COMPONENTS

Vacuum System



Cross section of the vacuum chamber through a dipole magnet.

The Most Important Features of the COSY Vacuum System:	
The entirely metallic vacuum chamber is made of high-alloy non-magnetic material.	
Total length of the vacuum chamber:	184 m.
Cross-section of vacuum chamber:	Circular (150 mm) Elliptic (150 x 60 mm)
Number of vacuum pumping stations:	app. 260
Bake-out temperature for the entire vacuum system:	300 deg. C.
Number of heating elements:	app. 1400
Final gas pressure in COSY:	$< 10^{-10}$ mbar.

Since particles circulating inside COSY travel long distances at various velocities, they may get lost when they are deflected or absorbed by atoms of the residual gas. An excellent vacuum is therefore required to ensure long storage times of the beam in COSY.

This requirement necessitates special technical efforts for the selection and treatment of the material and the production technology. Also a bake-out system has to be provided.

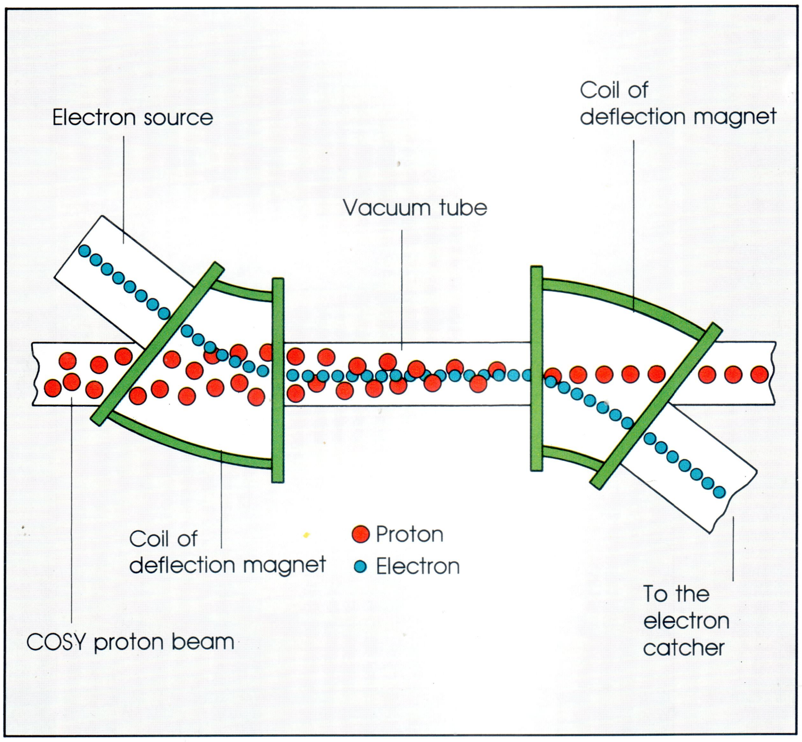
A simple comparison illustrates the quality of the COSY vacuum.

At normal air pressure a gas molecule would move about 1/10,000th of a millimetre before colliding with another molecule. At COSY pressure the gas molecule may travel 1000 km without colliding.

Electron Cooling

Already at the early commissioning stage of COSY electron cooling at injection energy will result in a brilliant COSY beam. Later this method will be applied at higher energies as well.

The mechanism of electron cooling is shown schematically in the figure. A monoenergetic, well-ordered and dense beam of electrons is injected by magnets to overlap with the COSY proton beam – which has a more irregular movement of its particles in comparison. In the mixing process the ordered movements of the electrons are transferred to the proton beam, which is thus "cooled" down and becomes well-ordered.

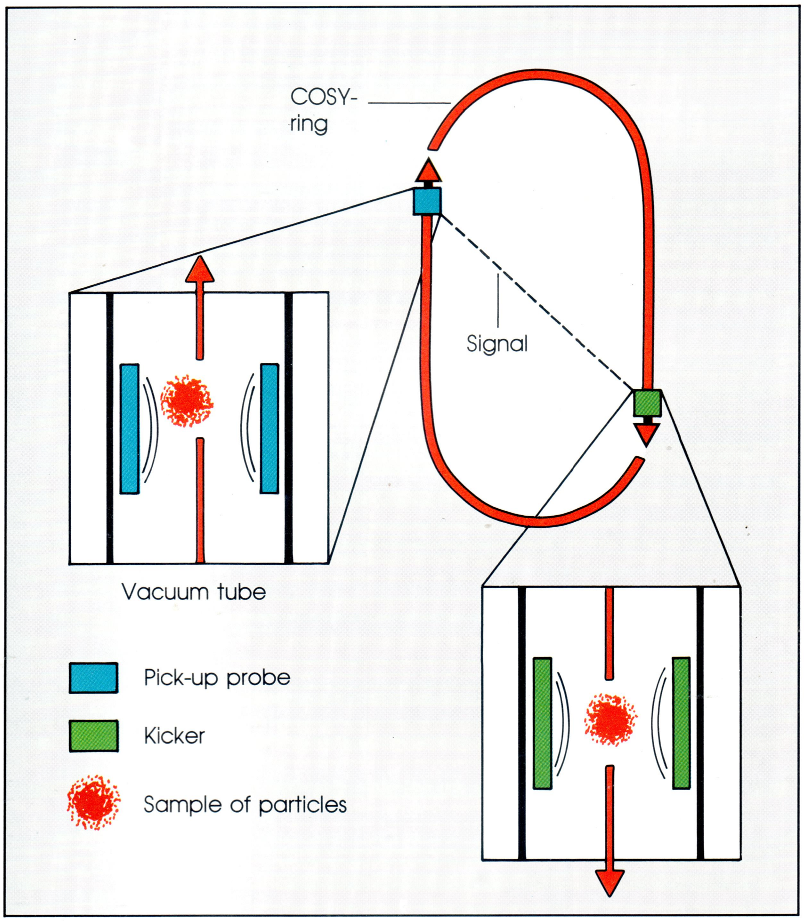


Principle of Electron Cooling

The electrons are deflected out of the ring after this short interaction (of a few metres) by another magnet. Each time the proton beam bunch reappears after a turn around COSY, the effect is repeated – about 1 million times per second – with the electrons cooling the protons down further.

Stochastic Cooling

At higher energies the stochastic cooling method will be applied to the COSY beam. In this case a small sample of particles of the COSY beam is studied with a pick-up probe to determine the position of the centre of gravity. If this is not on the ideal trajectory a correction signal is transmitted downstream to a kicker which kicks the sample into the correct position. As with electron cooling, this procedure is repeated every time the particle bunch passes the system, i. e. about 1 million times per second.



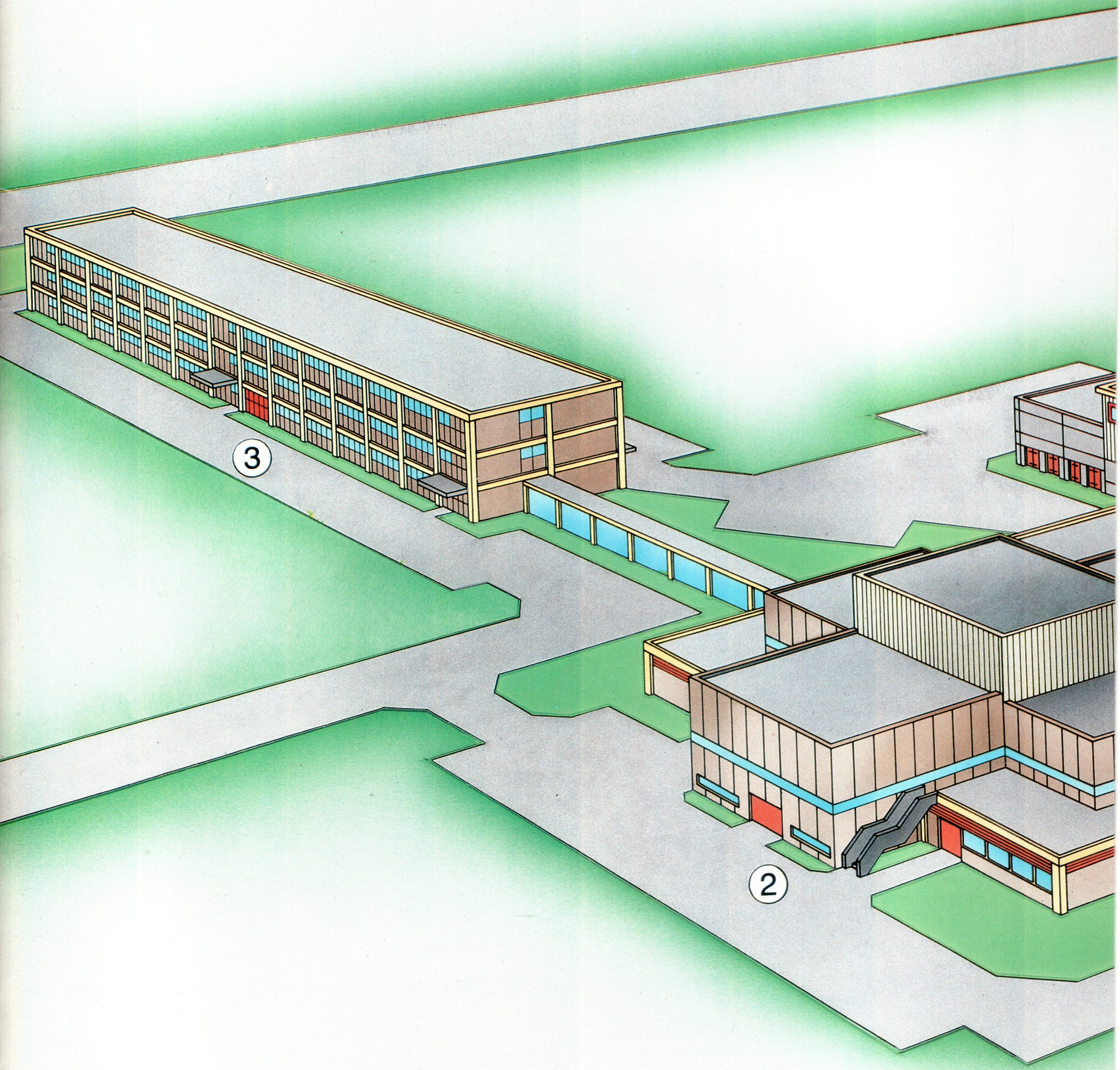
Stochastic Cooling

COSY – Buildings and Infrastructure

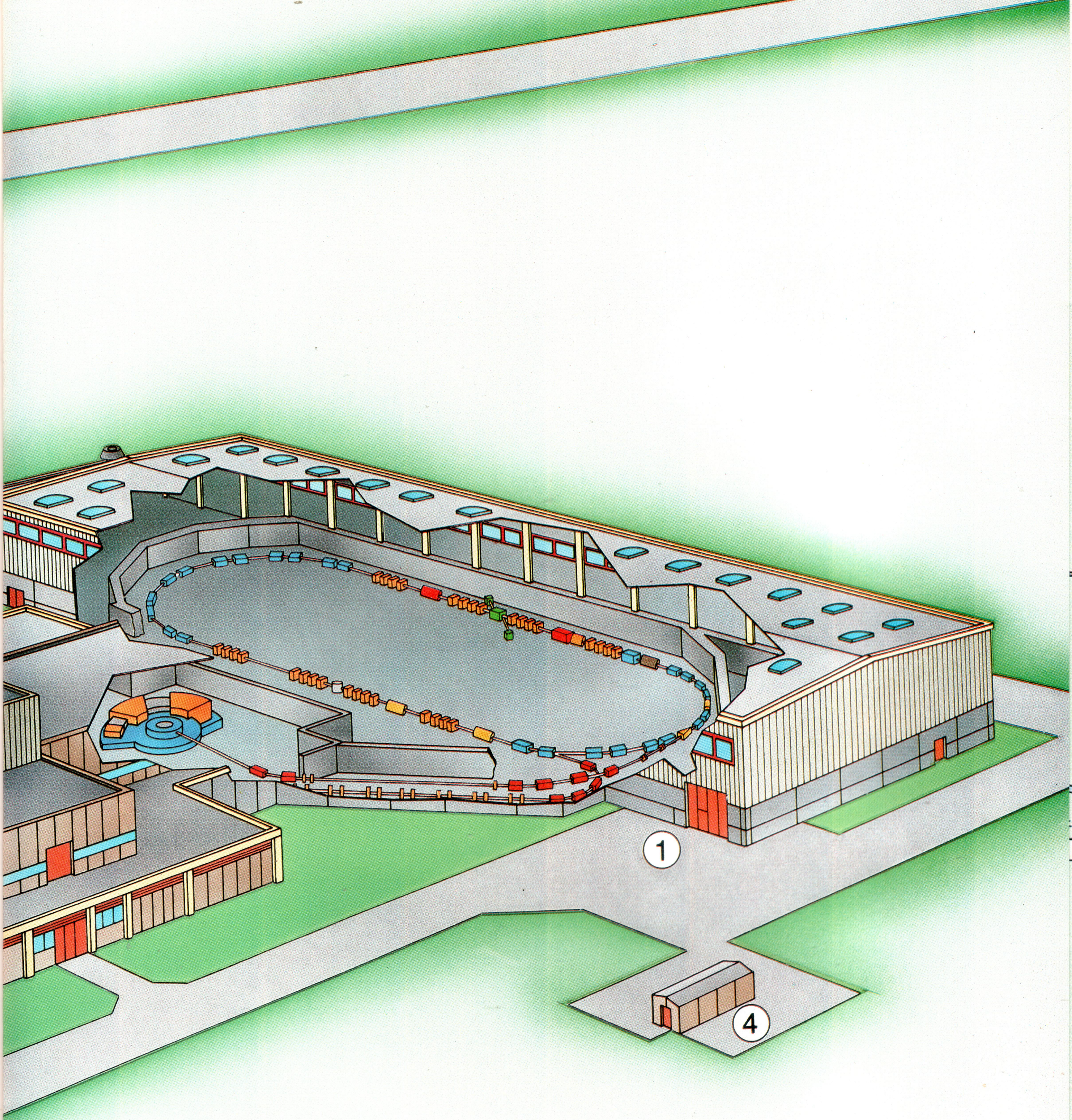
The foldout plan shows the COSY facility (1) and its connections to the existing cyclotron JULIC (2) of the Institute of Nuclear Physics (IKP) (3) on the site of the KFA Jülich.

The COSY ring with its annexes and target stations is housed in a building of about 104 times 41 metres – which has no basement. A basement is provided for the annex wing on the left side of the ring which accommodates all facilities to supply cooling and power, the computers and the control consoles as well as office space for experimenters. The main COSY hall is connected to the cyclotron building. The ground level of this wing – together with the existing experimental areas of the cyclotron – may be used for experimental setups. To the right are the injection line from the cyclotron and the extraction line to the external target stations. The upper storeys of this connecting wing house the power supplies and transformers for the magnets.

The mains power station (4) is shown on the right-hand side.



1 COSY facility
2 Cyclotron JULIC
3 Institute for Nuclear Physics (IKP)
4 Mains power station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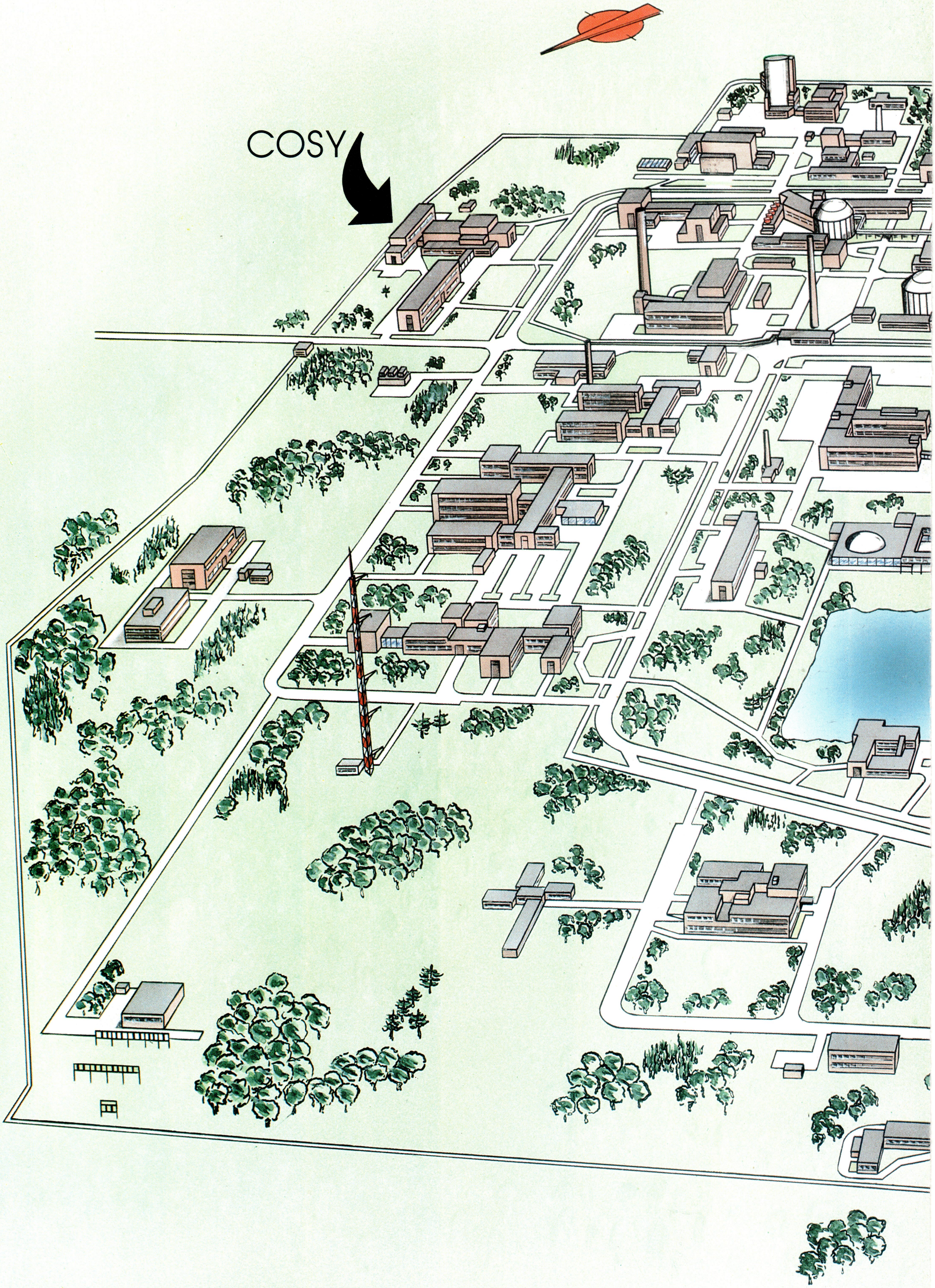
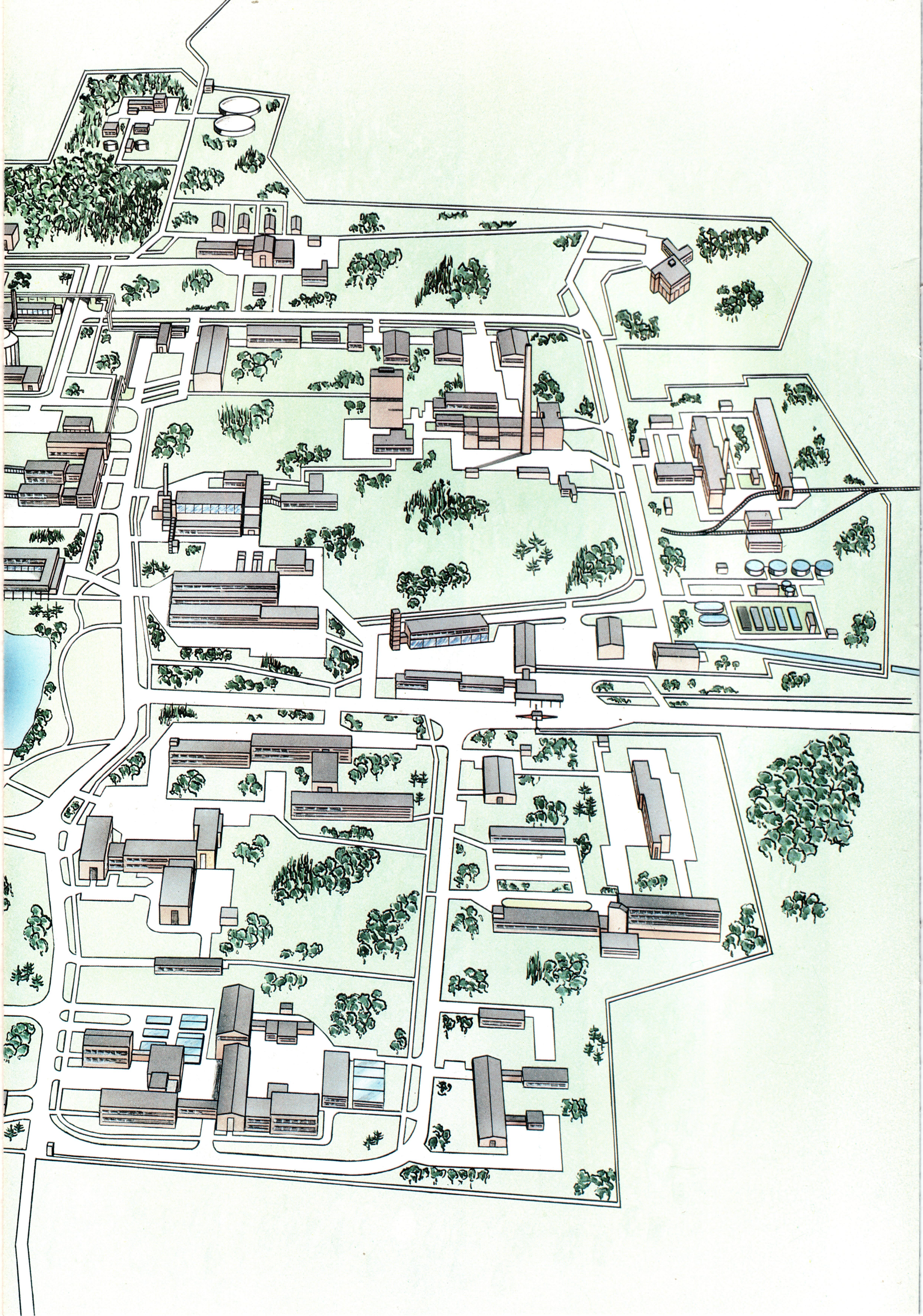

COSY



The Nuclear Research Center Jülich at a Glance

Name:	Kernforschungsanlage Jülich GmbH
Operator:	Federal Republic of Germany (90 %) State of North Rhine-Westphalia (10 %)
Staff:	4550, including 880 scientists and 60 professors
Visiting Scientists:	over 400 annually from more than 30 countries
Postgraduate Students:	160
Trainees:	400 in 24 professions
Area:	2.2 km^2
Annual Budget:	DM 500 million
Earnings:	DM 60 million
Legal Status:	KFA Jülich GmbH, a limited liability company, 90 % financed by the Federal Government and 10 % by the State of North Rhine-Westphalia
Bodies:	● Supervisory Board (comprising six representatives of the partners, three elected members of the KFA scientific and technical staff, three members of the scientific and business communities) ● Board of Directors ● Scientific and Technical Council (composed of heads of the institutes and projects, university representatives, elected members of the KFA scientific staff, one representative of the works council)
Scientific Infrastructure:	research reactor, isochronous cyclotron, compact cyclotron, biotechnical pilot plant, environmental specimen bank, laboratories for chemical analyses, electronics and general technology, four large-scale computers, hot cells, a laboratory for crystal materials development, an isotope separator, a meteorological tower, clinic with 24 beds, central library with more than 750,000 publications, etc.
Technical Infrastructure:	workshops, print shop, photographic services, decontamination unit, radiation protection unit, heat supply unit, coolant supply unit, helium liquefaction plant, fire prevention facilities, transport facilities, etc.
Scientific Publications:	approximately 130 Jülich research reports annually in KFA publication series and about 3000 contributions to scientific journals and publications
Training:	approximately 100 apprentices and trainees accepted annually, opportunities for academic degrees and professional qualification, advanced training
Social Facilities:	welfare office, housing service, two canteens, lecture facilities, company sports facilities, etc.
Public Relations:	approximately 18,000 visitors annually, four Saturdays open to visitors, representation at ten fairs, 40 national and international conferences and workshops, lectures at schools, public meetings and discussions, publications on selected energy topics.